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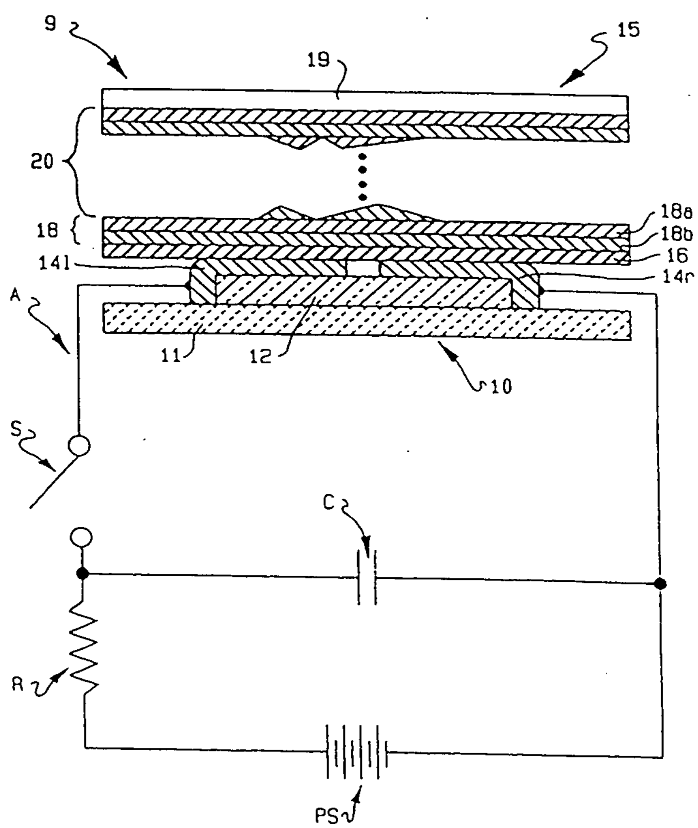
(54) Title: ENHANCED BRIDGE IGNITOR FOR IGNITION OF EXPLOSIVE AND ENERGETIC MATERIALS AND METHOD OF USE

(57) Abstract

An enhanced ignitor for initiating a quantity of pyrotechnic, explosive or energetic material including a multistage device in which the semiconductor bridge ignitor is activated by an electrical circuit and the ignitor in turn activates an energy-generating component which upon activation, alloys, crystallizes or otherwise reacts to create sufficient ignition energy to cause the pyrotechnic explosive or energetic material to ignite.



ENHANCED BRIDGE IGNITOR FOR IGNITION OF EXPLOSIVE AND ENERGETIC MATERIALS AND METHOD OF USE

Background of the Invention

Prior semiconductor bridge devices for the ignition of explosive and energetic materials have been proposed (U.S. Patent Nos. 3,366,055, 4,708,060, 4,976,200 and 5,029,529). Heat generated by semiconductor bridge ignitor devices has not in certain applications been sufficient to initiate the explosive or energetic material. The use of mixtures or layers of dissimilar materials which exhibit exothermic reactions when activated have been used extensively in the field of pyrotechnics to produce heat and light. Such dissimilar materials include metal-to-metal layers; metal-to-metal oxide layers and thermitic mixtures. Further, multilayer ignitors have been proposed (U.S. Patent No. 5,538,795).

The present invention proposes enhancing ignition of a bridge ignitor using such dissimilar materials.

Summary of the Invention

Broadly, the present invention is an enhanced ignitor and its method of construction and use comprising (1) a bridge ignitor and (2) an energy-generating component adjacent the bridge ignitor and activated by it. The energy-generating component in turn comprises at least two dissimilar materials which react exothermically and produce a self-sustaining reaction. The energy-generating component materials may be mixed together as a single layer or each material may be formed in a layer positioned adjacent to a layer of the other dissimilar material. Multiple single mixture layers or multiple pairs of such layers may also be constructed in stacks to enhance energy output.

Materials which exothermically react to produce a self-sustaining reaction include dissimilar elements, metallic or

non-metallic and mixtures of elements and compounds which compounds may be inorganic or organic.

The energy-generating component of the present invention is preferably constructed in a multilayered manner using integrated circuit design and semiconductor production techniques.

The enhanced bridge ignitor of the present invention is particularly useful in quickly generating sufficient heat to ignite pyrotechnics, explosives, propellants and other energetic materials. For example, gas generating materials located in automobile restraint inflator units may be ignited to effect inflation of air bags and inflatable seat belts used in vehicles.

The enhanced bridge ignitor of the present invention provides a readily manufactured ignitor. Both the bridge ignitor portion and the adjacent energy-generating component portion can be optimized by varying the composition, layer thickness, the number of layers and area to provide an enhanced ignitor for specific applications. The inventive ignitor may serve to ignite explosives of differing size and characteristics. Thus, the dimensions and geometric configuration of enhanced bridge ignitors of the present invention are each selected and sized for the energetic output required.

Brief Description of the Drawings

Fig. 1 is a sectional exploded view of the enhanced bridge ignitor of the present invention with an ignition circuit;

Fig. 2 is a sectional view of a dual layer of the energy-generating component of the invention; and

Fig. 3 is a sectional view of a tri-layer of the energy-generating component of the invention.

Description of the Preferred Embodiment

Referring to Fig. 1, enhanced bridge ignitor 9 includes nonelectrically conductive material substrate 11, doped semiconductor layer or bridge 12, right conductive land 14r and left conductive land 14l. Substrate 11, bridge 12 and lands 14r, 14l comprise a semiconductor bridge ignitor 10 which is preferably composed of a polysilicon-on-silicon wafer and suitable metallic land materials. Bridge ignitor 10 is enhanced by the addition of a multilayered energetic component 15. Nonconductive layer 16 is located between bridge ignitor 10 and multilayered energetic component 15 to electrically isolate the lands 14r and 14l from the multilayer energetic component 15. This electrical isolation prevents shunting of the bridge by the energy-generating component 15. The energy-generating component 15 is, in accordance with this invention, a component that creates heat when acted upon by the bridge ignitor. Component 15 may have the following characteristics.

1. A Single Layer or Multiple Layers With Each Layer Being A Mixture of Dissimilar Materials

The energy-generating component 15 may be a single layer composed of a thermitic mixture which mixture includes a metal oxide as the oxidizer and a metal. For example, a mixture of aluminum powder and powdered ion oxide which when heated by the bridge ignitor 10 in turn emits substantial heat. The production of such heat by two such powdered materials is a typical thermitic reaction. Such material is sold under the trademark Thermit. A plurality of layers of thermitic materials may also be used to increase total energy output. Other thermitic materials or thermites may be used include aluminothermic materials. Aluminum may be mixed with the following oxidizers:

Table I

Oxidizers	Formula
Boron oxide	B_2O_3
Chromium (III) oxide	Cr_2O_3
Manganese	MnO_2
Iron oxide	Fe_2O_3
Iron oxide	Fe_2O_4
Cupric oxide	CuO
Lead oxide	Pb_3O_4

Thermitic mixtures may include Fe_2O_3 mixed with the following elements of Table II to form the listed oxide compounds.

Table II

Combustible	Formula of Oxide
Al	Al_2O_3
Mg	MgO
Ca	CaO
Ti	TiO_2
Si	SiO_2
B	B_2O_3

2. A Pair of Layers With Each Layer Composed Of A Dissimilar Material

Component 15 may alternatively be a layer of one selected material positioned adjacent a layer of a selected dissimilar material which materials react exothermically to provide a self-sustaining reaction. A self-sustaining reaction is dictated primarily by two considerations: heat generated by reaction and limited heat transferred away from the reaction area.

Energetic-generating component 15 preferably includes one or more dual metallic component layers 18 with each dual layer 18 consisting of upper component metallic layer 18a and lower component metallic layer 18b. The thin metallic layers

of multilayered energetic component 15 are preferably deposited using vacuum deposition techniques. Layer 18a is preferably nickel or a nickel-based alloy and layer 18b is aluminum. Nickel-based alloys containing approximately 67% nickel and the balance copper with small amounts of other elements are useful in the practice of this invention. In addition to layers of nickel-based alloys and aluminum, any two metallic layers that produce an exothermic and sustaining alloying reaction may be used in the present invention.

Further examples of dissimilar metal layers and their reaction products are set out in Table III. For example, titanium reacts with carbon to form titanium carbide and titanium reacts with boron to form titanium diboride.

Table III

Metal In One Layer	Metal In Adjacent Layer	Compound Formed
Li	Sn	LiSn
Li	Sb	LiSb
U	Mg	UMg
Sn	Ca	$SnCa_2$
Ti	B	TiB_2
Zr	B	ZrB_2
Hf	B	HfB_2
Ti	Al	$TiZl_2$
Zr	Al	$ZrAl_2$
Ni	Al	NiAl
Pd	Al	PdAl
Pt	Al	PtAl
Ti	C	TiC
Zr	C	ZrC
V	Si	VSi_2
Nb	Si	$NbSi_2$
Ce	Pb	Ce_2Pb

Fig. 1 shows a first bi-metal layer 18 and a stack of layers above dual layer 18. For simplicity of illustration the additional bi-metal layers in stack 20 used in the practice of the invention are not individually shown. Further, such additional dual material layers serve to generate additional heat when raised in temperature are not necessary and it is within the scope of this invention to use only one dual layer.

3. Metal Layer and Adjacent Metal Compound Layer

Other dual layer energetic materials may be used as component 15 in the practice of this invention such as active metals (or metal fuels) and metal oxides. The metal fuels and metal compounds such as oxides are selected as pairs of such materials that chemically combine to create an exothermic and self-sustaining reaction. An example of such a pair of materials is aluminum and iron oxide. Component 15 may be a thin layer of aluminum adjacent a thin layer of iron oxide. Such dual or pair layers may be repeated to form a stack, similar to stack 20 of metallic-to-metallic dual layers 18.

Other metals which are useful in forming a metallic layer are iron, magnesium, titanium, tungsten, zinc and zirconium.

Other metal oxides that are useful in forming a metal oxide layer are set out in the following Table.

Table IV

Compound	Formula
Aluminum oxide	Al_2O_3
Barium oxide	BaO
Boron oxide	B_2O_3
Magnesium oxide	MgO
Potassium chloride	KCl
Potassium oxide	K_2O
Silicon dioxide	SiO_2
Sodium chloride	NaCl
Sodium oxide	Na_2O
Strontium oxide	SrO
Titanium dioxide	TiO_2
Zirconium dioxide	ZrO_2

4. <u>A Metal Layer And An Adjacent Non-Metallic Layer</u>

It is also further contemplated that a layer of zirconium and a layer of silicon may be used as disclosed in U.S. Patent No. 4,783,379 which patent is incorporated by reference and is made a part of this application.

5. <u>A Metal Layer And An Adjacent Organic Material Layer</u>

Component 15 may as a further alternative, include a thin layer of magnesium and an adjacent thin layer of polytetrafluoroethylene PTFE. This material is sold under the trademark Enerfoil. This material may be produced by vacuum deposition techniques and is described in U.S. Patents 4,890,860, 5,034,070 and 5,253,584 which patents are incorporated by reference and are part of the present application.

6. <u>Non-Metallic Layer and Reactive Layer</u>

Component 15 may be composed of a non-metallic layer of boron, carbon, phosphorus (P), phosphor (P_4), silicon or sulfur. The adjacent reaction layer includes any compound to

react with the non-metallic layer to give off heat such as a suitable oxygen compound.

7. Material Tri-Layers

As a further alternative embodiment, the multilayer energetic component 15 may consist of one or more tri-layers such as a layer of metal fuel, a layer of metal oxide and a layer of carbon between the first two mentioned layers. Further, tri-layers useful in component 15 are composed of a reactive layer, such as aluminum, and a second active material such as copper oxide which reactive layers are separated by a third nonreactive or much less reactive layer of material such as carbon. The presence of the separator layer enhances the reaction resulting in generation of higher temperatures. This multilayer material is disclosed in U.S. Patent No. 5,505,799 which is incorporated by reference and is made part of the present application.

The energy-generating component 15 may include any of the materials described above under numbers 1-7 or any other materials which react to produce heat in a sustaining manner such that when component 15 is activated by bridge 10, component 15 will produce sufficient heat to ignite the explosive or energetic material to be initiated. Finally, component 15 may be constructed of combinations of mixtures and layers described above.

Stack 20 may include hundreds of pairs of stacked bi-metal layers including five hundred (500) pairs or more. Bi-metal layers are positioned adjacent one another. For example, a layer of nickel or a nickel-based alloy is positioned adjacent a layer of aluminum followed by another layer of nickel or nickel-based alloy and another layer of aluminum and so forth to form a stack 20. Stack 20 of such layers, numbering in the hundreds or more, are used depending on the amount of energy required to initiate the explosive or energetic material 19. This stacked composite including dual

layers 18 of bi-metal layers normally functions in sequence. The lowest dual layer 18 adjacent bridge 12 being heated first to a sufficient temperature to cause layers 18a and 18b to exothermically alloy. Heat produced by the alloying of layers 18a and 18b causes the alloying (heat-generating) process to propagate the lowest layer of stack 20 in a self-sustaining reaction process. This self-sustaining process continues through subsequent layers of the stack until the heat generated causes initiation of energetic material 19.

Further, with respect to Fig. 1, bridge initiator 10 includes a circuit A connected to lands 14r and 14l including a switch S, a capacitor C, a resistor R, and a power supply PS. Fig. 2 shows a dual layer of aluminum 25 and a nickel-based alloy 26, and Fig. 3 shows a tri-layer of aluminum 27, carbon 28 and copper oxide 29.

In the operation of the enhanced bridge ignitor 9, switch S of circuit A is closed by an external signal, generated, for example, by a vehicle restraint system's electronic control module in response to rapid deceleration resulting from a crash. Closure of switch S causes the electrical charge stored in capacitor C to produce a voltage drop between lands 14r and 14l. Electrical current flow induced by the voltage drop causes ohmic heating of the bridge ignitor 10, resulting in initiation of component 15. In the Fig. 1 embodiment initiation is the start of the alloying reaction in the nearest bi-metallic layer 18 of multilayered energetic component 15. Bridge ignitor 10 activates to accomplish one or more of the following: (1) generates heat through burning; (2) forms a plasma or (3) creates a shock effect. Self propagating exothermic reaction of subsequent bi-metallic mulitlayers 18 in stack 20 as described above, produces further heat which in turn initiates the gas generating energetic material 19.

Example

A composite stack of pairs of layers of aluminum and nickel consisting of one hundred and fifty (150) pairs of layers with each layer having the following dimensions was fabricated.

length:	0.045 inches	1.142 mm (millimeters)
width:	0.055 inches	1.397 mm
thickness:	250 nm (nanometers)	

Such composite stack produced an amount of energy equal to 908.3 mJ when activated, as compared to 3 mJ (milli Joules) of energy produced by a standard semiconductor bridge alone.

Dual metallic layer 18 and all other stack layers have critical temperatures at which explosive crystallization takes place. Dual metallic layer 18 and other layers of stack 20 undergo an alloying reaction also known as explosive crystallization when heated to its critical temperature. The heat generated by the metallic layers is many times greater than the heat generated by bridge 10.

I CLAIM:

1. A device for initiating a quantity of pyrotechnic, explosive or other energetic material comprising

a) a bridge ignitor capable of producing heat when activated;

b) an energy-generating component positioned adjacent the bridge and adjacent the energetic material, such component in turn comprising dissimilar materials which combine to produce heat in a self-sustaining manner such that the quantity of energetic material is initiated; and

c) circuit means for activating such bridge ignitor;

whereby the quantity of energetic material when positioned adjacent the energy-generating component of the device is initiated upon operation of the circuit means to activate the bridge ignitor.

2. The device of claim 1 in which the energy-generating component is a thermitic material.

3. The device of claim 1 in which the energy-generating component is a dual metallic layer.

4. The device of claim 1 in which the energy-generating component is a dual layer with one layer being a metal and the other a metal oxide.

5. The device of claim 1 in which the energy-generating device is a dual layer with one layer being a metal and the other an organic material.

6. The device of claim 1 in which the energy-generating component is a dual layer with one layer including a non-metallic material and the adjacent layer including an oxide.

7. The device of claim 1 in which the energy-generating component has a plurality of stacked dual layers.

8. The device of claim 3 in which the dual layers are a nickel alloy and aluminum.

9. The device of claim 3 in which the dual layer is a metal fuel and a metal oxide.

10. The device of claim 3 in which the dual layer is magnesium and polytetrafluoroethylene.

11. The device of claim 6 in which the energy-generating component is a plurality of stacked dual layers of two dissimilar metals.

12. The device of claim 6 in which the energy-generating component is a plurality of stacked dual layers of metallic materials.

13. The device of claim 6 in which the energy-generating component is a tri-layer composite of metal fuel and metal oxide separated by carbon.

14. The device of claim 2 in which the energy-generating component is a single layer of a mixture of aluminum powder and powdered oxide.

15. The device of claim 1 in which the energy-generating component is a layer of non-metallic material and an adjacent reactive layer.

16. A device for initiating a quantity of pyrotechnic, explosive or energetic material comprising

a) a semiconductor bridge ignitor capable of producing heat when activated;

b) a component positioned adjacent the semiconductor bridge comprising two dissimilar materials which when heated enter into an exothermic reaction; and

c) circuit means for activating such semiconductor bridge ignitor;

whereby the quantity of pyrotechnic, explosive or energetic material positioned adjacent the alloying component of the device is initiated upon operation of the circuit means.

17. A method of initiating a quantity of pyrotechnic, explosive or other energetic material comprising

1) positioning adjacent such quantity of pyrotechnic, explosive or energetic material an energy-generating component including two dissimilar materials which enter into an exothermic reaction when heated;

2) positioning adjacent such energy-generating component a bridge ignitor; and

3) providing means to cause the bridge ignitor to react and form heat to cause said component to enter into such exothermic reaction

whereby the heat from the bridge ignitor causes the adjacent energy-generating component to activate in turn cause the

quantity of pyrotechnic, explosive or energetic material to ignite.

18. The method of claim 17 in which the energy-generating component is provided with a thermitic material.

19. The method of claim 17 in which the energy-generating component is provided with a dual metallic layer.

20. The method of claim 17 in which the energy-generating component is provided with a dual layer of a metal and a dissimilar material.

21. The method of claim 17 in which the energy-generating component is provided with mulitlayers of reactive material.

22. The method of claim 21 in which the multilayer energy-generating component is provided with a plurality of stacked dual layers.

23. The method of claim 19 in which the dual layers include a layer of nickel alloy and a layer of aluminum.

24. The method of claim 20 in which the dual layer is a metal fuel and a metal oxide which react to generate heat.

25. The method of claim 20 in which the dual layer is magnesium and polytetrafluoroethylene.

26. The method of claim 22 in which the energy-generating component is a plurality of stacked dual layers of metallic materials.

27. The method of claim 17 in which the energy-generating component is a tri-layer composite of metal fuel and metal oxide separated by carbon.

28. The method of claim 18 in which the thermitic material is a single layer of a mixture of aluminum powder and powdered oxide.

29. The method of claim 17 in which the energy-generating component is a plurality of stacked tri-layers of fuel, metal oxide and carbon.

30. The method of claim 21 in which the semiconductor bridge and energy-generating component are constructed by depositing layer upon layer.

31. The method of claim 17 in which the energetic material is a material in a vehicle inflator.

32. The method of claim 17 in which the bridge ignitor and energy-generating component layers are provided with dimensions and number of layers to provide the amount of ignition energy required to cause the energetic material to combust.

33. The device of claim 6 in which the semiconductor bridge and energy-generating component are constructed by depositing layer upon layer.

34. A vehicle inflator including the device of claim 1.

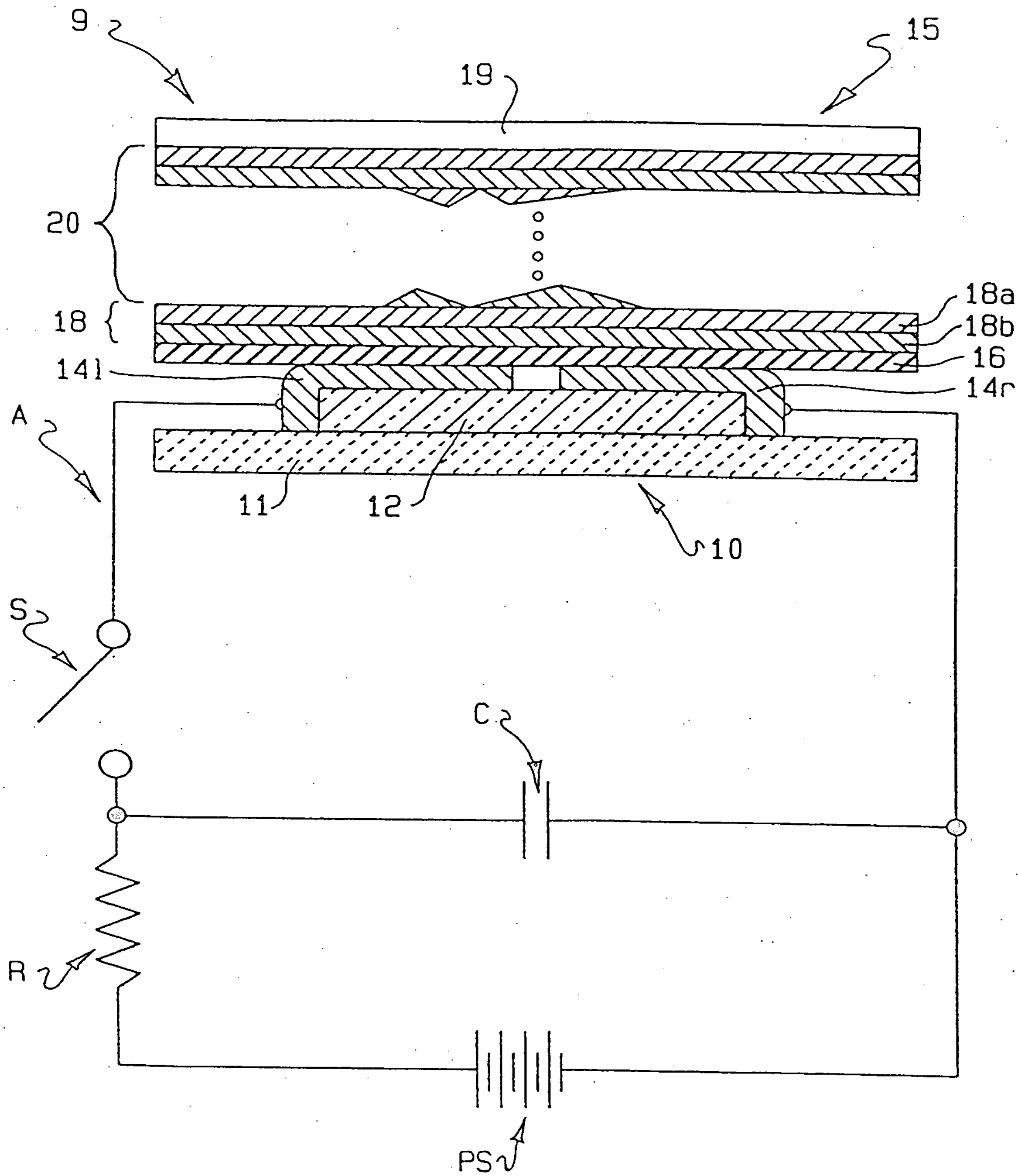


FIG. 1

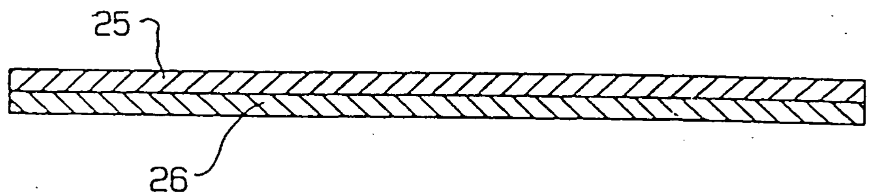


FIG. 2

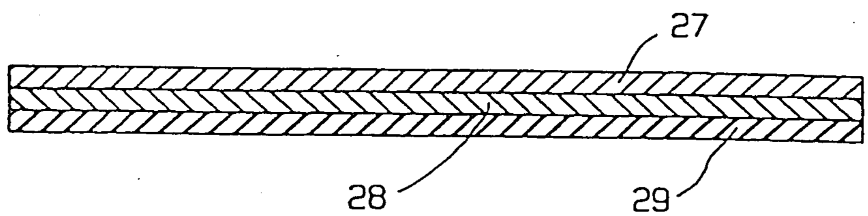


FIG. 3

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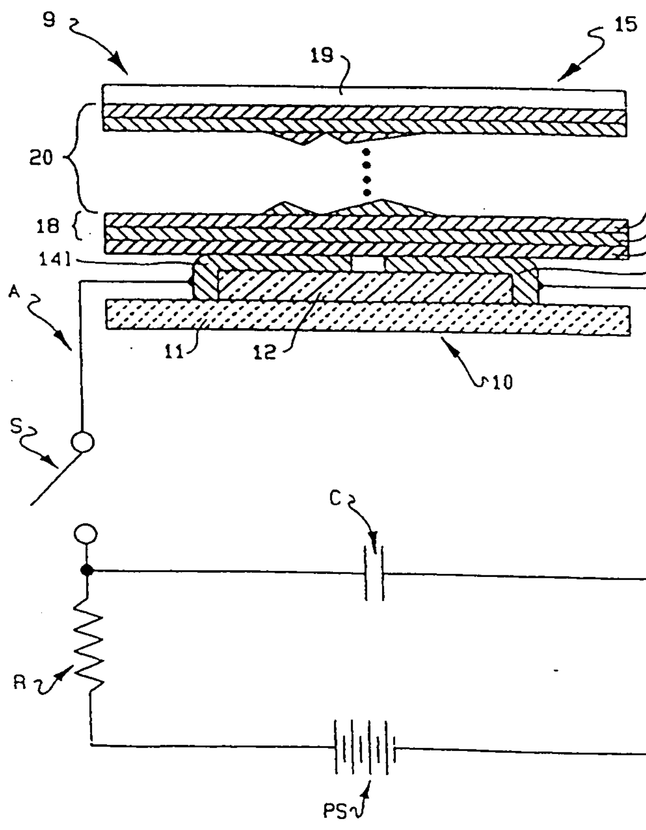

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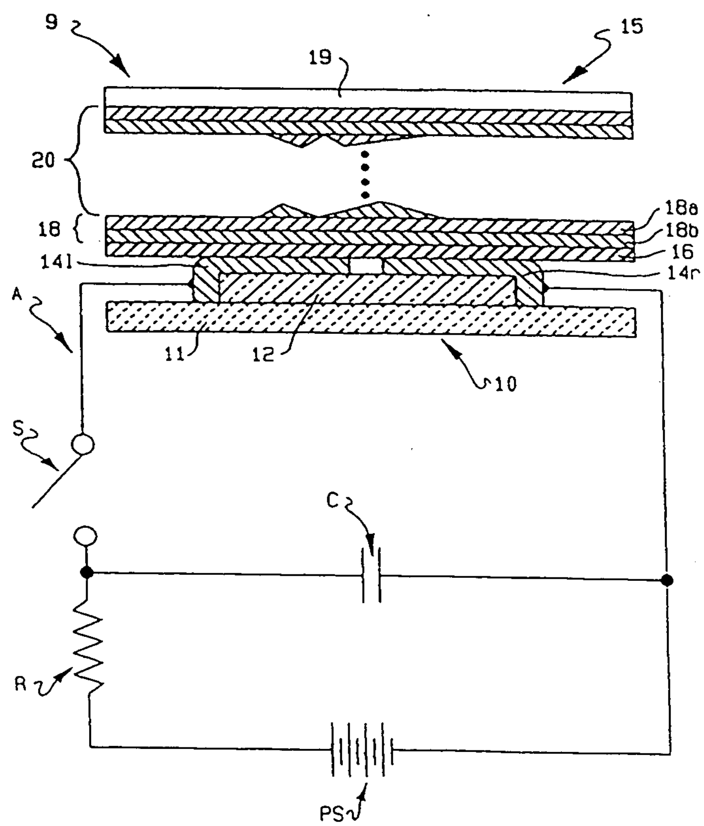

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FI	Finland
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GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IL	Israel
IS	Iceland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgyzstan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakstan
LC	Saint Lucia
LI	Liechtenstein
LK	Sri Lanka
LR	Liberia
LS	Lesotho
LT	Lithuania
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
MK	The former Yugoslav Republic of Macedonia
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
MX	Mexico
NE	Niger
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SN	Senegal
SZ	Swaziland
TD	Chad
TG	Togo
TJ	Tajikistan
TM	Turkmenistan
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The present invention proposes enhancing ignition of a bridge ignitor using such dissimilar materials.

Summary of the Invention

Broadly, the present invention is an enhanced ignitor and its method of construction and use comprising (1) a bridge ignitor and (2) an energy-generating component adjacent the bridge ignitor and activated by it. The energy-generating component in turn comprises at least two dissimilar materials which react exothermically and produce a self-sustaining reaction. The energy-generating component materials may be mixed together as a single layer or each material may be formed in a layer positioned adjacent to a layer of the other dissimilar material. Multiple single mixture layers or multiple pairs of such layers may also be constructed in stacks to enhance energy output.

Materials which exothermically react to produce a self-sustaining reaction include dissimilar elements, metallic or

non-metallic and mixtures of elements and compounds which compounds may be inorganic or organic.

The energy-generating component of the present invention is preferably constructed in a multilayered manner using integrated circuit design and semiconductor production techniques.

The enhanced bridge ignitor of the present invention is particularly useful in quickly generating sufficient heat to ignite pyrotechnics, explosives, propellants and other energetic materials. For example, gas generating materials located in automobile restraint inflator units may be ignited to effect inflation of air bags and inflatable seat belts used in vehicles.

The enhanced bridge ignitor of the present invention provides a readily manufactured ignitor. Both the bridge ignitor portion and the adjacent energy-generating component portion can be optimized by varying the composition, layer thickness, the number of layers and area to provide an enhanced ignitor for specific applications. The inventive ignitor may serve to ignite explosives of differing size and characteristics. Thus, the dimensions and geometric configuration of enhanced bridge ignitors of the present invention are each selected and sized for the energetic output required.

Brief Description of the Drawings

Fig. 1 is a sectional exploded view of the enhanced bridge ignitor of the present invention with an ignition circuit;

Fig. 2 is a sectional view of a dual layer of the energy-generating component of the invention; and

Fig. 3 is a sectional view of a tri-layer of the energy-generating component of the invention.

Description of the Preferred Embodiment

Referring to Fig. 1, enhanced bridge ignitor 9 includes nonelectrically conductive material substrate 11, doped semiconductor layer or bridge 12, right conductive land 14r and left conductive land 14l. Substrate 11, bridge 12 and lands 14r, 14l comprise a semiconductor bridge ignitor 10 which is preferably composed of a polysilicon-on-silicon wafer and suitable metallic land materials. Bridge ignitor 10 is enhanced by the addition of a multilayered energetic component 15. Nonconductive layer 16 is located between bridge ignitor 10 and multilayered energetic component 15 to electrically isolate the lands 14r and 14l from the multilayer energetic component 15. This electrical isolation prevents shunting of the bridge by the energy-generating component 15. The energy-generating component 15 is, in accordance with this invention, a component that creates heat when acted upon by the bridge ignitor. Component 15 may have the following characteristics.

1. A Single Layer or Multiple Layers With Each Layer Being A Mixture of Dissimilar Materials

The energy-generating component 15 may be a single layer composed of a thermitic mixture which mixture includes a metal oxide as the oxidizer and a metal. For example, a mixture of aluminum powder and powdered ion oxide which when heated by the bridge ignitor 10 in turn emits substantial heat. The production of such heat by two such powdered materials is a typical thermitic reaction. Such material is sold under the trademark Thermit. A plurality of layers of thermitic materials may also be used to increase total energy output. Other thermitic materials or thermites may be used include aluminothermic materials. Aluminum may be mixed with the following oxidizers:

Table I

Oxidizers	Formula
Boron oxide	B_2O_3
Chromium (III) oxide	Cr_2O_3
Manganese	MnO_2
Iron oxide	Fe_2O_3
Iron oxide	Fe_2O_4
Cupric oxide	CuO
Lead oxide	Pb_3O_4

Thermitic mixtures may include Fe_2O_3 mixed with the following elements of Table II to form the listed oxide compounds.

Table II

Combustible	Formula of Oxide
Al	Al_2O_3
Mg	MgO
Ca	CaO
Ti	TiO_2
Si	SiO_2
B	B_2O_3

2. A Pair of Layers With Each Layer Composed Of A Dissimilar Material

Component 15 may alternatively be a layer of one selected material positioned adjacent a layer of a selected dissimilar material which materials react exothermically to provide a self-sustaining reaction. A self-sustaining reaction is dictated primarily by two considerations: heat generated by reaction and limited heat transferred away from the reaction area.

Energetic-generating component 15 preferably includes one or more dual metallic component layers 18 with each dual layer 18 consisting of upper component metallic layer 18a and lower component metallic layer 18b. The thin metallic layers

of multilayered energetic component 15 are preferably deposited using vacuum deposition techniques. Layer 18a is preferably nickel or a nickel-based alloy and layer 18b is aluminum. Nickel-based alloys containing approximately 67% nickel and the balance copper with small amounts of other elements are useful in the practice of this invention. In addition to layers of nickel-based alloys and aluminum, any two metallic layers that produce an exothermic and sustaining alloying reaction may be used in the present invention.

Further examples of dissimilar metal layers and their reaction products are set out in Table III. For example, titanium reacts with carbon to form titanium carbide and titanium reacts with boron to form titanium diboride.

Table III

Metal In One Layer	Metal In Adjacent Layer	Compound Formed
Li	Sn	LiSn
Li	Sb	LiSb
U	Mg	UMg
Sn	Ca	$SnCa_2$
Ti	B	TiB_2
Zr	B	ZrB_2
Hf	B	HfB_2
Ti	Al	$TiZl_2$
Zr	Al	$ZrAl_2$
Ni	Al	NiAl
Pd	Al	PdAl
Pt	Al	PtAl
Ti	C	TiC
Zr	C	ZrC
V	Si	VSi_2
Nb	Si	$NbSi_2$
Ce	Pb	Ce_2Pb

Fig. 1 shows a first bi-metal layer 18 and a stack of layers above dual layer 18. For simplicity of illustration the additional bi-metal layers in stack 20 used in the practice of the invention are not individually shown. Further, such additional dual material layers serve to generate additional heat when raised in temperature are not necessary and it is within the scope of this invention to use only one dual layer.

3. Metal Layer and Adjacent Metal Compound Layer

Other dual layer energetic materials may be used as component 15 in the practice of this invention such as active metals (or metal fuels) and metal oxides. The metal fuels and metal compounds such as oxides are selected as pairs of such materials that chemically combine to create an exothermic and self-sustaining reaction. An example of such a pair of materials is aluminum and iron oxide. Component 15 may be a thin layer of aluminum adjacent a thin layer of iron oxide. Such dual or pair layers may be repeated to form a stack, similar to stack 20 of metallic-to-metallic dual layers 18.

Other metals which are useful in forming a metallic layer are iron, magnesium, titanium, tungsten, zinc and zirconium.

Other metal oxides that are useful in forming a metal oxide layer are set out in the following Table.

Table IV

Compound	Formula
Aluminum oxide	Al_2O_3
Barium oxide	BaO
Boron oxide	B_2O_3
Magnesium oxide	MgO
Potassium chloride	KCl
Potassium oxide	K_2O
Silicon dioxide	SiO_2
Sodium chloride	NaCl
Sodium oxide	Na_2O
Strontium oxide	SrO
Titanium dioxide	TiO_2
Zirconium dioxide	ZrO_2

4. A Metal Layer And An Adjacent Non-Metallic Layer

It is also further contemplated that a layer of zirconium and a layer of silicon may be used as disclosed in U.S. Patent No. 4,783,379 which patent is incorporated by reference and is made a part of this application.

5. A Metal Layer And An Adjacent Organic Material Layer

Component 15 may as a further alternative, include a thin layer of magnesium and an adjacent thin layer of polytetrafluoroethylene PTFE. This material is sold under the trademark Enerfoil. This material may be produced by vacuum deposition techniques and is described in U.S. Patents 4,890,860, 5,034,070 and 5,253,584 which patents are incorporated by reference and are part of the present application.

6. Non-Metallic Layer and Reactive Layer

Component 15 may be composed of a non-metallic layer of boron, carbon, phosphorus (P), phosphor (P_4), silicon or sulfur. The adjacent reaction layer includes any compound to

react with the non-metallic layer to give off heat such as a suitable oxygen compound.

7. Material Tri-Layers

As a further alternative embodiment, the multilayer energetic component 15 may consist of one or more tri-layers such as a layer of metal fuel, a layer of metal oxide and a layer of carbon between the first two mentioned layers. Further, tri-layers useful in component 15 are composed of a reactive layer, such as aluminum, and a second active material such as copper oxide which reactive layers are separated by a third nonreactive or much less reactive layer of material such as carbon. The presence of the separator layer enhances the reaction resulting in generation of higher temperatures. This multilayer material is disclosed in U.S. Patent No. 5,505,799 which is incorporated by reference and is made part of the present application.

The energy-generating component 15 may include any of the materials described above under numbers 1-7 or any other materials which react to produce heat in a sustaining manner such that when component 15 is activated by bridge 10, component 15 will produce sufficient heat to ignite the explosive or energetic material to be initiated. Finally, component 15 may be constructed of combinations of mixtures and layers described above.

Stack 20 may include hundreds of pairs of stacked bi-metal layers including five hundred (500) pairs or more. Bi-metal layers are positioned adjacent one another. For example, a layer of nickel or a nickel-based alloy is positioned adjacent a layer of aluminum followed by another layer of nickel or nickel-based alloy and another layer of aluminum and so forth to form a stack 20. Stack 20 of such layers, numbering in the hundreds or more, are used depending on the amount of energy required to initiate the explosive or energetic material 19. This stacked composite including dual

layers 18 of bi-metal layers normally functions in sequence. The lowest dual layer 18 adjacent bridge 12 being heated first to a sufficient temperature to cause layers 18a and 18b to exothermically alloy. Heat produced by the alloying of layers 18a and 18b causes the alloying (heat-generating) process to propagate the lowest layer of stack 20 in a self-sustaining reaction process. This self-sustaining process continues through subsequent layers of the stack until the heat generated causes initiation of energetic material 19.

Further, with respect to Fig. 1, bridge initiator 10 includes a circuit A connected to lands 14r and 141 including a switch S, a capacitor C, a resistor R, and a power supply PS. Fig. 2 shows a dual layer of aluminum 25 and a nickel-based alloy 26, and Fig. 3 shows a tri-layer of aluminum 27, carbon 28 and copper oxide 29.

In the operation of the enhanced bridge ignitor 9, switch S of circuit A is closed by an external signal, generated, for example, by a vehicle restraint system's electronic control module in response to rapid deceleration resulting from a crash. Closure of switch S causes the electrical charge stored in capacitor C to produce a voltage drop between lands 14r and 141. Electrical current flow induced by the voltage drop causes ohmic heating of the bridge ignitor 10, resulting in initiation of component 15. In the Fig. 1 embodiment initiation is the start of the alloying reaction in the nearest bi-metallic layer 18 of multilayered energetic component 15. Bridge ignitor 10 activates to accomplish one or more of the following: (1) generates heat through burning; (2) forms a plasma or (3) creates a shock effect. Self propagating exothermic reaction of subsequent bi-metallic mulitlayers 18 in stack 20 as described above, produces further heat which in turn initiates the gas generating energetic material 19.

Example

A composite stack of pairs of layers of aluminum and nickel consisting of one hundred and fifty (150) pairs of layers with each layer having the following dimensions was fabricated.

length:	0.045 inches	1.142 mm (millimeters)
width:	0.055 inches	1.397 mm
thickness:	250 nm (nanometers)	

Such composite stack produced an amount of energy equal to 908.3 mJ when activated, as compared to 3 mJ (milli Joules) of energy produced by a standard semiconductor bridge alone.

Dual metallic layer 18 and all other stack layers have critical temperatures at which explosive crystallization takes place. Dual metallic layer 18 and other layers of stack 20 undergo an alloying reaction also known as explosive crystallization when heated to its critical temperature. The heat generated by the metallic layers is many times greater than the heat generated by bridge 10.

I CLAIM:

1. A device for initiating a quantity of pyrotechnic, explosive or other energetic material comprising

a) a bridge ignitor capable of producing heat when activated;

b) an energy-generating component positioned adjacent the bridge and adjacent the energetic material, such component in turn comprising dissimilar materials which combine to produce heat in a self-sustaining manner such that the quantity of energetic material is initiated; and

c) circuit means for activating such bridge ignitor;

whereby the quantity of energetic material when positioned adjacent the energy-generating component of the device is initiated upon operation of the circuit means to activate the bridge ignitor.

2. The device of claim 1 in which the energy-generating component is a thermitic material.

3. The device of claim 1 in which the energy-generating component is a dual metallic layer.

4. The device of claim 1 in which the energy-generating component is a dual layer with one layer being a metal and the other a metal oxide.

5. The device of claim 1 in which the energy-generating device is a dual layer with one layer being a metal and the other an organic material.

6. The device of claim 1 in which the energy-generating component is a dual layer with one layer including a non-metallic material and the adjacent layer including an oxide.

7. The device of claim 1 in which the energy-generating component has a plurality of stacked dual layers.

8. The device of claim 3 in which the dual layers are a nickel alloy and aluminum.

9. The device of claim 3 in which the dual layer is a metal fuel and a metal oxide.

10. The device of claim 3 in which the dual layer is magnesium and polytetrafluoroethylene.

11. The device of claim 6 in which the energy-generating component is a plurality of stacked dual layers of two dissimilar metals.

12. The device of claim 6 in which the energy-generating component is a plurality of stacked dual layers of metallic materials.

13. The device of claim 6 in which the energy-generating component is a tri-layer composite of metal fuel and metal oxide separated by carbon.

14. The device of claim 2 in which the energy-generating component is a single layer of a mixture of aluminum powder and powdered oxide.

15. The device of claim 1 in which the energy-generating component is a layer of non-metallic material and an adjacent reactive layer.

16. A device for initiating a quantity of pyrotechnic, explosive or energetic material comprising

a) a semiconductor bridge ignitor capable of producing heat when activated;

b) a component positioned adjacent the semiconductor bridge comprising two dissimilar materials which when heated enter into an exothermic reaction; and

c) circuit means for activating such semiconductor bridge ignitor;

whereby the quantity of pyrotechnic, explosive or energetic material positioned adjacent the alloying component of the device is initiated upon operation of the circuit means.

17. A method of initiating a quantity of pyrotechnic, explosive or other energetic material comprising

1) positioning adjacent such quantity of pyrotechnic, explosive or energetic material an energy-generating component including two dissimilar materials which enter into an exothermic reaction when heated;

2) positioning adjacent such energy-generating component a bridge ignitor; and

3) providing means to cause the bridge ignitor to react and form heat to cause said component to enter into such exothermic reaction

whereby the heat from the bridge ignitor causes the adjacent energy-generating component to activate in turn cause the

quantity of pyrotechnic, explosive or energetic material to ignite.

18. The method of claim 17 in which the energy-generating component is provided with a thermitic material.

19. The method of claim 17 in which the energy-generating component is provided with a dual metallic layer.

20. The method of claim 17 in which the energy-generating component is provided with a dual layer of a metal and a dissimilar material.

21. The method of claim 17 in which the energy-generating component is provided with mulitlayers of reactive material.

22. The method of claim 21 in which the multilayer energy-generating component is provided with a plurality of stacked dual layers.

23. The method of claim 19 in which the dual layers include a layer of nickel alloy and a layer of aluminum.

24. The method of claim 20 in which the dual layer is a metal fuel and a metal oxide which react to generate heat.

25. The method of claim 20 in which the dual layer is magnesium and polytetrafluoroethylene.

26. The method of claim 22 in which the energy-generating component is a plurality of stacked dual layers of metallic materials.

27. The method of claim 17 in which the energy-generating component is a tri-layer composite of metal fuel and metal oxide separated by carbon.

28. The method of claim 18 in which the thermitic material is a single layer of a mixture of aluminum powder and powdered oxide.

29. The method of claim 17 in which the energy-generating component is a plurality of stacked tri-layers of fuel, metal oxide and carbon.

30. The method of claim 21 in which the semiconductor bridge and energy-generating component are constructed by depositing layer upon layer.

31. The method of claim 17 in which the energetic material is a material in a vehicle inflator.

32. The method of claim 17 in which the bridge ignitor and energy-generating component layers are provided with dimensions and number of layers to provide the amount of ignition energy required to cause the energetic material to combust.

33. The device of claim 6 in which the semiconductor bridge and energy-generating component are constructed by depositing layer upon layer.

34. A vehicle inflator including the device of claim 1.

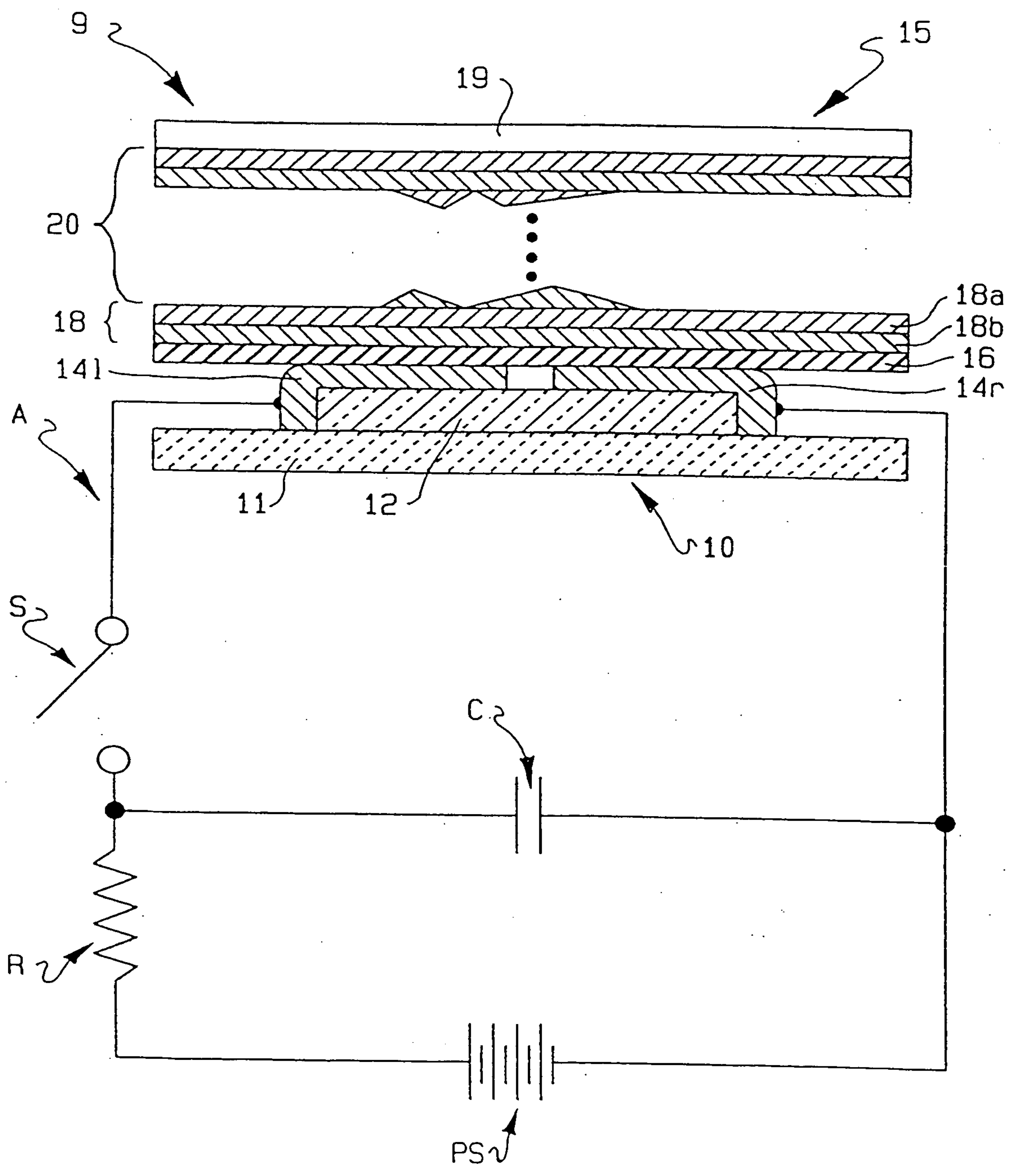

FIG. 1

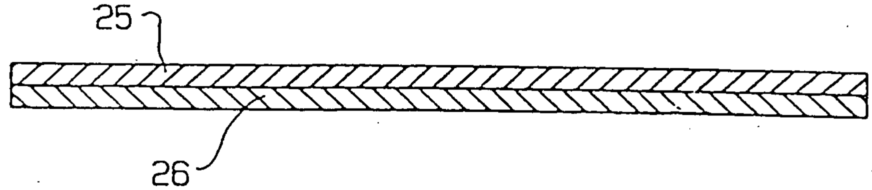

FIG. 2

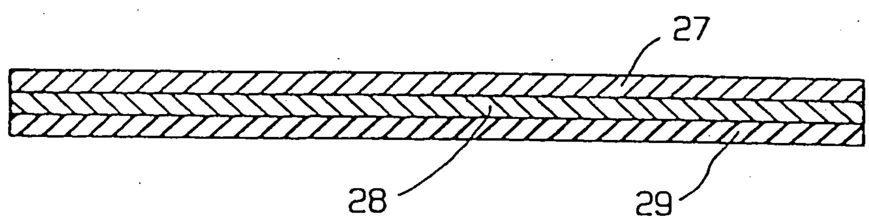

FIG. 3

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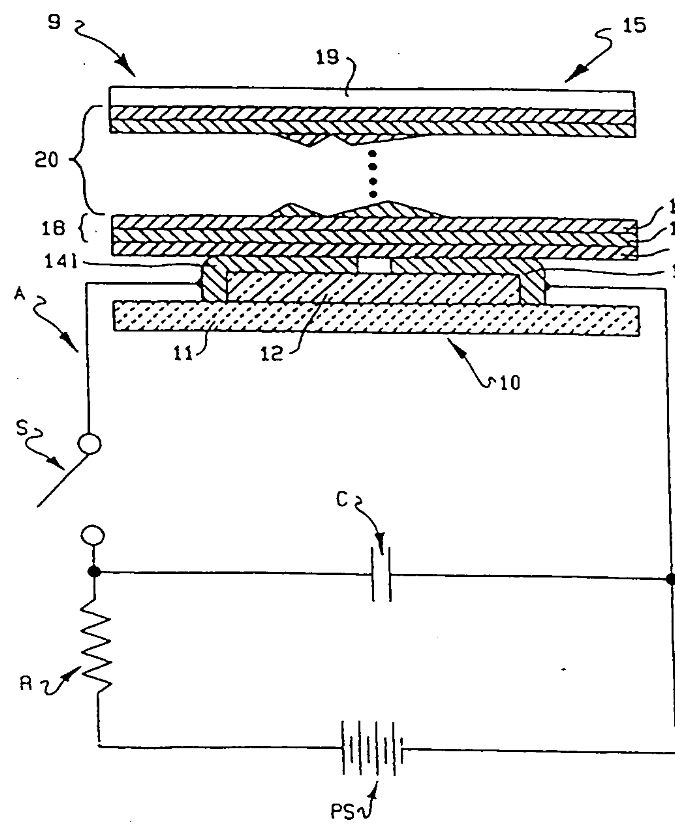
(54) Title: ENHANCED BRIDGE IGNITOR FOR IGNITION OF EXPLOSIVE AND ENERGETIC MATERIALS AND METHOD OF USE

(57) Abstract

An enhanced ignitor for initiating a quantity of pyrotechnic, explosive or energetic material including a multistage device in which the semiconductor bridge ignitor (10) is activated by an energy-generating component (15) which upon activation alloys, crystallizes or otherwise reacts to create sufficient ignition energy to cause the pyrotechnic explosive or energetic material to ignite.



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/01185

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :F42C 19/12
US CL :102/202.7, 202.8, 202.9, 202.5
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 102/202.7, 202.8, 202.9, 202.5

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS
search terms: 102/clas and thermit?

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4,989,515 A (KELLY et al) 05 February 1991 (05/02/91), see column 2, lines 44-50, and Figure 1.	1,2,14,17, 18,28
X	US 5,403,036 A (ZAKULA et al) 04 April 1995 (04/04/95), see column 5, lines 25-33 and Figure 4.	1,2,17,18, 31,34
X	US 4,708,060 A (BICKES, Jr. et al) 24 November 1987 (24/11/87), see column 4, lines 9-22, TABLE 3, and Figure 2b.	16
A	US 3,882,324 A (SMOLKER et al) 06 May 1975 (06/05/75), see column 2, lines 41-61.	2,14,16,18,28
A	US 3,666,967 A (KEISTER et al) 30 May 1972(30/05/72), see column 1, lines 9-26 and Figure 1.	1, 2, 14, 16, 17,18,28

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 JULY 1998	19 AUG 1998

Name and mailing address of the ISA/US	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/01185

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 9,10,12,13
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

Please See Extra Sheet.

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1,2,14,16-18,28,31,34

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/01185

BOX I. OBSERVATIONS WHERE CLAIMS WERE FOUND UNSEARCHABLE
2. Where no meaningful search could be carried out, specifically:

Claims 9 and 10 depend from claim 3, which requires that the energy generating component be a dual metallic layer. However claim 9 states that the layer is a metal/oxide layer, and claim 10 states that the layer is a metal/polymer layer. Claim 12 and 13 depend from claim 6, and the layers recited in claims 12 and 13 are inconsistent with that of claim 6.

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING
This ISA found multiple inventions as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I, claims 1,2,14,16,17,18,28,31 and 34, drawn to igniters using a powder explosive energy-generating component.
Group II, claims 1,3,7,8,16,17,19-23,26,30-32 and 34, drawn to igniters having layers of non-oxidizing metallic reactive materials.
Group III, claims 1,4-7,11,16,17,20-22,24,25,27 and 29-34, drawn to igniters having layers of oxidizing reactive materials.
Group IV, claims 1,15-17,31,32 and 34, drawn to igniters having non-metallic materials which ignite with a reactive layer.

The following statements concern claims which recite subject matter common to more than one of groups I-IV:

The features recited in claims 1,17,21,22,31,32 and 34 are inherent to the disclosure of U.S. patent 3,880,595 to Timmerman.

The features recited in claims 1,17,21,22,31,32 and 34 are inherent to the disclosure of U.S. patent 5,351,619 to Chan et al.

The stacked dual layer feature recited in claims 7,20 and 22 is shown by U.S. patent 5,090,322 to Allford.

The use of a semiconductive bridge in an igniter, as claimed in claims 16 and 30, is well known.

The inventions listed as Groups I and II, Groups I and III, and Groups I and IV, do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: there is no special technical feature common to the groups, as the common subject matter between groups I and II, I and III, and I and IV, recited in claims 1,16,17,31 and 34 is shown by Timmerman and Chan et al, with the use of an SCB well known.

The inventions listed as Groups II and III do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: there is no special technical feature common to both groups, as the common subject matter of claims 1,7,16,17,20-22,30-32 and 34 is shown by Timmerman, Chan et al, and Allford, with the use of an SCB well known.

The inventions listed as Groups II and IV do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: there is no special technical feature common to both groups, as the common subject matter of claims 1,16,17,31,32 and 34 is shown by Timmerman and Chan et al, with the use of an SCB well known.

The inventions listed as Groups III and IV do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: there is no special technical feature common to both groups, as the common subject matter of claims 1,16,17,31,32 and 34 is shown by Timmerman and Chan et al, with the use of an SCB well known.